cm-3, the silicon layer having a thickness between the first side and the second side, the thickness of the silicon layer being 30 nm; a platinum layer deposited on the first side of the silicon layer; a first heterojunction interface between the silicon layer and the platinum layer; a cobalt layer deposited on the second side of the silicon layer; and a second heterojunction interface between the silicon layer and the cobalt layer.

[0011] In yet another aspect of the present disclosure, a n-type metal-semiconductor-metal heterojunction diode (MSM diode) comprises: a silicon layer having a first side and a second side opposite the first side, a surface of the first side being doped with phosphorus at a surface concentration of 2×10^{20} cm-3, the silicon layer having a thickness between the first side and the second side, the thickness of the silicon layer being 60 nm; a first chromium layer deposited on the first side of the silicon layer; a first heterojunction interface between the first chromium layer and the silicon layer; a second chromium layer deposited on the second side of the silicon layer; and a second heterojunction interface between the second chromium layer and the silicon layer.

[0012] The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE FIGURES

[0013] FIG. **1** shows an example of a metal-semiconductor-metal (MSM) heterojunction diode.

[0014] FIGS. **2***a-d* show examples of energy band diagrams for different MSM diodes.

[0015] FIG. **3** is a flowchart of a process for fabricating a MSM diode.

[0016] FIG. **4** shows side views of a MSM diode during different stages of fabrication.

[0017] FIG. **5** is a graph showing examples of current density versus voltage (J-V) characteristics for MSM diodes with and without surface doping.

[0018] FIG. **6** is a graph showing examples of J-V characteristics for different MSM diodes and a Schottky diode.

[0019] FIGS. **7***a-c* show examples of energy band diagrams corresponding to the different MSM diodes of FIG. **6**.

[0020] FIG. **7***d* shows an example of an energy band diagram corresponding to the Schottky diode of FIG. **6**.

DETAILED DESCRIPTION

[0021] FIG. **1** shows an example of a metal-semiconductor-metal (MSM) heterojunction diode **100**. As shown in FIG. **1**, a MSM diode **100** includes a thin layer of semiconductor **102** positioned between two metal electrodes **104** and **106**. The semiconductor **102** may be a crystalline semiconductor, e.g., a single-crystal crystalline semiconductor, or a polycrystalline semiconductor. A thickness **116** of the semiconductor **102** is based on, e.g., close or comparable to, a mean free path of charge carriers, which may result in near ballistic carrier transport across the semiconductor layer **102**. Heterojunctions **112** and **114** of the MSM diode **100** may include two contact interfaces and energy barriers on opposite sides of the semiconductor layer **102**. Asymmetric energy band structures are formed by either selecting different materials for the metals **104** and **106** or by selectively doping one side of the semiconductor layer **102**.

[0022] The MSM heterojunction diode **100** may be constructed using suitable semiconductor and metal materials. The semiconductor **102** can be, but is not limited to, silicon (Si), germanium (Ge), silicon germanium (SiGe), aluminum antimonide (AlSb), gallium antimonide (GaSb), gallium arsenide (GaAs), indium antimonide (InSb), indium arsenide (InAs), indium gallium arsenide (InGaAs), indium phosphide (InP), cadmium selenide (CdSe), cadmium telluride (CdTe), lead sulfide (PbS), and lead telluride (PbTe). The metals **104** and **106** on either side of the semiconductor **102** can be, but are not limited to, silver (Ag), aluminum (Al), gold (Au), cobalt (Co), chromium (Cr), copper (Cu), gadolinium (Gd), hafnium (Hf), indium (In), iridium (Ir), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), palladium (Pd), platinum (Pt), rhodium (Rh), tantalum (Ta), titanium (Ti), tungsten (W), and zinc (Zn). Other suitable materials different than those listed above may be used. A cut-off frequency of a MSM diode may be configured by selecting different combinations of semiconductor and metal materials.

[0023] FIGS. **2***a-d* show examples of energy band diagrams **200**, **210**, **220**, and **230** for different MSM diodes. In the energy band diagrams **200**, **210**, **220**, and **230**, h^+ and e^- represent the charge carriers emitted into the semiconductor layer in a direction shown by the arrows **202**, **212**, **222**, and **232**. FIGS. **2***a* and **2***b* show energy band diagrams **200** and **210** for p-type MSM diodes. FIGS. **2***c* and **2***d* show energy band diagrams **220** and **230** for n-type MSM diodes. FIG. **2***a* depicts a p-type MSM diode that includes different materials for metals M1 and M2. FIG. **2***c* depicts a n-Type MSM diode that includes different materials for metals M3 and M4. FIG. **2***b* depicts a p-type MSM diode that includes a semiconductor that is selectively doped on one side. FIG. **2***d* depicts a n-type MSM diode that includes a semiconductor that is selectively doped on one side. For the MSM diodes of FIGS. **2***b* and **2***d* having one-side selective doping of the semiconductor, metals M5 and M6 may be the same material, and metals M7 and M8 may be the same material.

[0024] FIG. **3** is a flowchart of a process **300** for fabricating a MSM diode. Briefly, the process **300** includes selective doping of a surface of a semiconductor of a layered substrate, e.g., a semiconductor-on-insulator (SOI) wafer (**302**), depositing a first metal on a first side of the semiconductor (**304**), bonding the first side of the semiconductor to a carrier wafer to position the first metal between the semiconductor and the carrier wafer (**306**), selectively removing other layers of the layered substrate, e.g., a bulk semiconductor substrate layer and an electrical insulator layer, to expose a second side of the semiconductor (**308**), and depositing a second metal on the second side of the semiconductor (**310**).

[0025] FIG. **4** shows side views of a MSM diode during different stages (a)-(f) of fabrication. The MSM diode that includes a thin single-crystal semiconductor layer, e.g., silicon (Si) layer **401**, of desired thickness, doping profile, and crystal orientation is provided (stage (a)). The MSM diode can be fabricated on a wafer scale.

[0026] A flip-bond technique may be used so that different metal layers can be patterned and deposited onto both sides of the thin semiconductor layer **401** of a layered substrate, e.g., a standard silicon-on-insulator (SOI) wafer **400** that includes a silicon layer **401**, an insulator (e.g., SiO_2) layer **402**, and a bulk silicon substrate **403**. MSM heterojunctions can be fabricated from the SOI wafer **400** using selective chemical or plasma etches so that an individual layer of desired material, e.g., silicon layer **401**, can be obtained and positioned